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Short communication

PREDICTIVE MODELS ON SETTLEMENT PARAMETERS OF CLAYEY SOILS: A CASE STUDY IN PORT-HARCOURT CITY OF NIGERIA

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ABSTRACT

Settlement parameters of shallow foundations placed on clayey soils have been studied in PortHarcourt City of Nigeria. Fifty soil samples were obtained from six locations and subsequently subjected to oedometer tests. Settlement parameters of void ratio,e, coefficient of volume compressibility, m_v, and compression modulus, E_c, were deduced from oedometer results. Results of e, and m_v generally showed a decreasing trend with increase in pressure, while E_c increases with pressure. Predictive models relating void ratio and pressure, coefficient of volume compressibility and pressure, and that of compression modulus and pressure, were subsequently formulated. The generated models can be used for quick evaluation of settlement input parameters required in settlement analysis of foundation placed on cohesive soil formation.

Keywords: Void ratio, compression modulus, volume compressibility, foundation.

INTRODUCTION

The deformation tendency of foundation placed on saturated cohesive soils is time dependent. Usually, both immediate and consolidation settlement are assessed to determine if the expected deformation is within the tolerance limit of the superstructure. Details on limiting settlement criteria for shallow foundations placed on either cohesive or granular soils have been presented by scholars (Polshin and Tokar, 1957; Wahls, 1981; Skempton and McDonald, 1956, Murthy, 2007). Evaluation of immediate settlement of shallow foundation placed on cohesive soils requires knowledge of the undrained modulus, E_u, of the supporting soil. However, determination of E_u is faced with several challenges. Barnes (2000) and Jamiolkowski *et al*. (1979) proposed ratio of undrained modulus to undrained cohesion (E_u/c_u) depending on over consolidation ratio and plasticity index. Butler (1974) proposed E_u/c_u ratio of 400 for over consolidated London clay, while Bjerrum (1973) proposed c_u/p ratios in the range of 500 to 1500 for normally consolidated clays. Smith (1984) reported Skempton (1951) to have presented a procedure of obtaining undrained modulus directly from triaxial test results by determining the strain corresponding to 65% of the maximum deviator stress and dividing this value to the corresponding stress. In many literatures, E_u for various soils is presented in a wide range of values (Bowles, 1997).

In consolidation settlement, soil parameters such as void ratio, e, and coefficient of volume compressibility, m_v, of the compressible soil formation that is significantly affected by the foundation induced vertical stress are required. The void ratio of a soil expresses the ratio of volume of void to volume of solid (Barnes, 2000), while coefficient of volume compressibility is the compression of a soil layer per unit of original thickness due to a given unit increase in pressure (Raj, 2008).The reciprocal of m_v is compression modulus, E_c, and is analogous to Youngs modulus (Garg, 1987). In Tomlinson (2001), the various range of coefficient of volume compressibility of soils is given and usually**,** the settlement parameters are derived from results of oedometer test with details of test procedure in BS 1377. Based on the difficulty in evaluating the relevant settlement parameters required in computing foundation settlement, an attempt is made in this paper to develop predictive models in the study area to aide preliminary analysis and design of shallow foundations placed on clayey soils.

MATERIALS AND METHODS

Data Aquisition / Analysis

A total of fifty soil samples were obtained from borings to depth of 5m at six different areas of PortHarcourt; Eagle Island, Agip, East West Road, Abuloma, Rumuigbo, and PortHarcourt Town. Soil samples were subjected to oedometer test from which void ratio and coefficient of volume compressibility of each soil sample were

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evaluated using the following equations (Smith, 1984; Raj, 2008).

$$e_1 = \frac{H_1}{\frac{M_s}{AG\rho_W}} - 1 \quad (1)$$

$$m_v = \frac{1}{1+e_0}\left(\frac{e_0 - e_1}{p_1 - p_0}\right) = \frac{1}{1+e_0}\left(\frac{\Delta e}{\Delta p}\right) \quad (2)$$

Where H_1 is thickness at the end of any increment period, M_s is mass of sample measured at the end of test, A is area of specimen, G is specific gravity of soil sample, ρ_w is density of water, e_1 is void ratio corresponding to pressure p_1, e_0 is void ratio corresponding to pressure p_o, m_v is coefficient of volume compressibility, Δe and Δp are change in void ratio and pressure respectively.

The average values of void ratios and coefficient of volume compressibility of soil samples were obtained for varying pressure range on each study area. Subsequently, the following relationships were evaluated; void ratio versus pressure, coefficient of volume compressibility versus pressure and reciprocal of coefficient of volume compressibility versus pressure.

RESULTS AND DISCUSSION

Void Ratio and Pressure Variation

The variation of void ratio and pressure is depicted in figure 1. Here, the trend lines are closely related, depicting a gradual decrease in void ratio (e) as pressure increases for Rumuigbo, Agip, Eagle Island, East West Road and Port Harcourt Town. Values of void ratio ranged between 0.80-0.40 for pressure range of 0-800kN/m^2 respectively in these five areas and m_v values are indicative of medium compressibility soils. In Abuloma, the soils also had a gradual decrease in void ratio as pressure increased but higher e values are associated with this area.

The model equations expressing variation of void ratio versus pressure for each study area are given as follows:

Abuloma: $e = -3E\text{-}09p^3+4E\text{-}06p^2-0.002p+1.444$; $R^2=0.996$ (3)
East West Road: $e = -5E\text{-}10p^3+9E\text{-}07p^2+0.737$; $R^2=0.999$ (4)
Rumuigbo: $e = -5E\text{-}10p^3+9E\text{-}07p^2+0.737$; $R^2=0.999$ (5)
PortHarcourt Town: $e = 2E\text{-}07p^2+0.617$; $R^2=0.981$ (6)
Eagle Island: $e = -7E\text{-}10p^3+1E\text{-}06p^2+0.583$; $R^2=0.998$ (7)
Agip: $e = -7E\text{-}07p^2+0.617$; $R^2=0.981$ (8)

Coefficient of Volume Compressibility and Pressure Variation

In figure 2, the variation of coefficient of volume compressibility and pressure is shown. The trend lines showed a rapid decrease in m_v through a pressure range of 0-100kN/m^2, beyond which m_v had a gradual decrease as pressure increased. The Abuloma area had higher values of m_v compared to the other five areas of study, for any pressure range. At pressures exceeding 100kN/m^2, the compressibility characteristics of soils within Rumuigbo, Agip, East West Road, Eagle Island and Port Harcourt Town areas showed very close approximation. Generally, m_v values are indicative of medium compressibility soils.

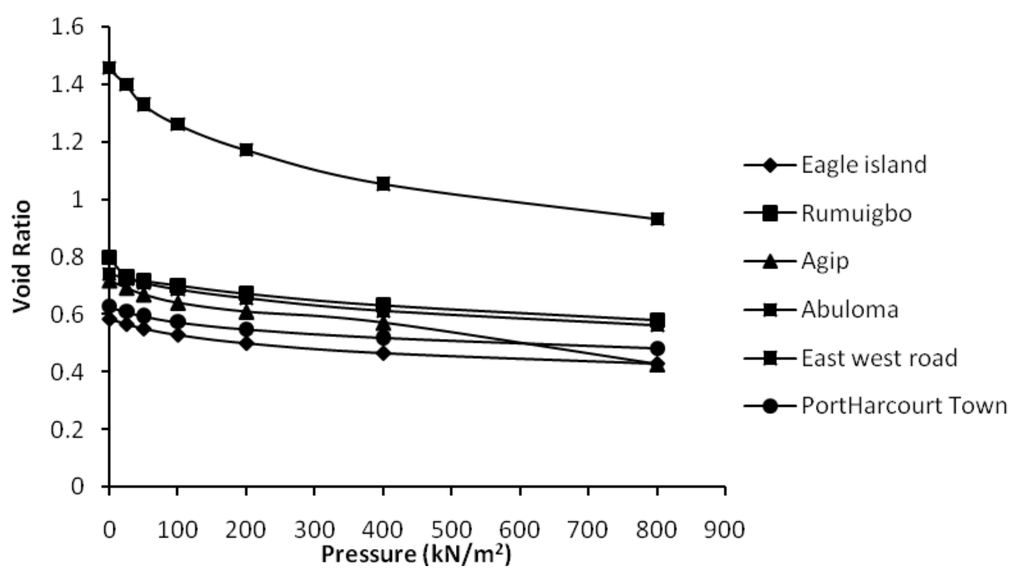

Fig. 1. Variation of void ratio versus pressure.

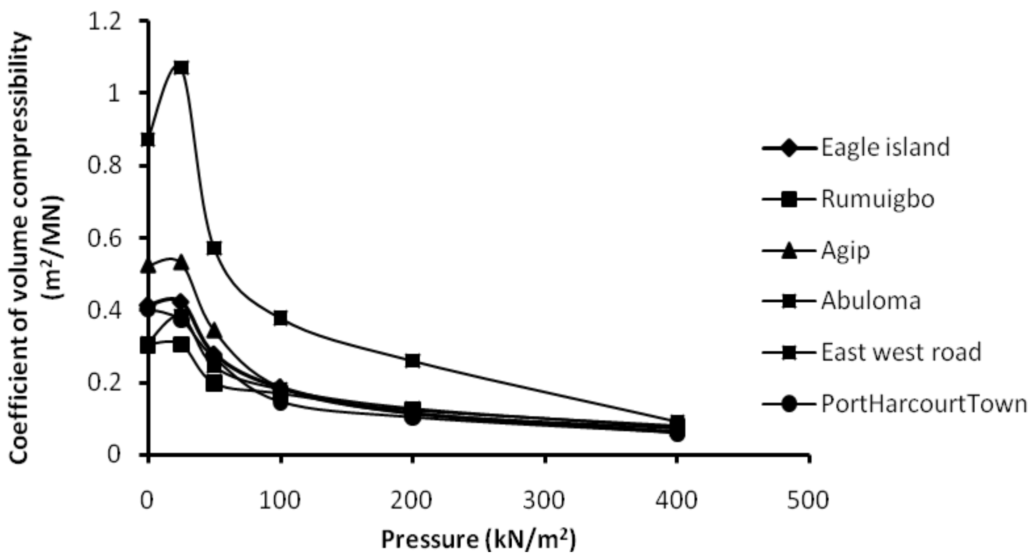

Fig. 2. Variation of coefficient of volume compressibility versus Pressure.

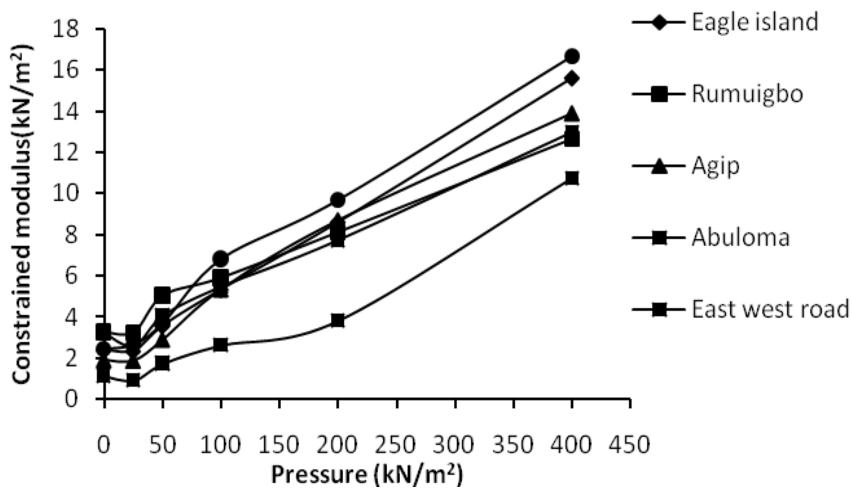

Fig. 3. Variation of Compression modulus versus Pressure.

The predictive models relating coefficient of volume compressibility and pressure are presented in Equations (9-14).

Eagle Island: $m_v = -1E\text{-}08p^3 + 1E\text{-}05p^2 - 0.0035p + 0.4444$ (9)

Rumuigbo: $m_v = -1E\text{-}08p^3 + 9E\text{-}06p^2 - 0.0023p + 0.3197$ (10)

Agip: $m_v = -2E\text{-}08p^3 + 2E\text{-}05p^2 - 0.0051p + 0.5682$ (11)

Abuloma: $m_v = -3E\text{-}08p^3 + 3E\text{-}05p^2 - 0.008p + 0.9997$ (12)

East West Road: $m_v = 2E\text{-}06p^2 - 0.0016p + 0.3461$ (13)

Port Harcourt Town: $m_v = -2E\text{-}08p^3 + 1E\text{-}05p^2 - 0.0039p + 0.4235$ (14)

Compression modulus versus Pressure

The variation of compression modulus, E_c, and pressure is depicted in figure 3, where E_c increased with pressure and the values are easily predictable at pressures exceeding 100kN/m^2. Soils from PortHarcourt town exhibited the highest values of compression modulus while Abuloma area had lowest values at pressures exceeding 100kN/m^2.

The predictive models relating compression modulus and pressure in the six areas are presented in Equations (15-20) as follows:

Eagle Island: $1/m_v = 7E\text{-}06p^2 + 0.031p$

Table 1. Model calibration of void ratio.

Location	Pressure 100kN/m^2		Pressure 200kN/m^2		Pressure 400kN/m^2	
	e measured	e predicted	e measured	e predicted	e measured	e predicted
Eagle island	0.530	0.592	0.501	0.617	0.466	0.787
Rumuigbo	0.702	0.737	0.673	0.769	0.632	0.849
Agip	0.640	0.610	0.609	0.589	0.571	0.505
Abuloma	1.261	1.281	1.173	1.180	1.055	1.092
East west road	0.687	0.746	0.657	0.769	0.614	0.849
Port Harcourt Town	0.574	0.619	0.549	0.625	0.519	0.649

Table 2. Model calibration of coefficient of volume compressibility.

Location	Pressure 100kN/m^2		Pressure 200kN/m^2		Pressure 400kN/m^2	
	m_v measured	m_v predicted	m_v measured	m_v predicted	m_v measured	m_v predicted
Eagle island	0.187	0.184	0.116	0.164	0.064	**0.004**
Rumuigbo	0.169	0.169	0.123	0.139	0.079	**-**
Agip	0.187	0.248	0.115	0.188	0.072	**-**
Abuloma	0.379	0.469	0.261	0.359	0.093	**-**
East west road	0.182	0.206	0.129	0.106	0.077	**0.026**
Port Harcourt Town	0.146	0.113	0.103	0.063	0.060	-

Table 3. Model calibration of compression modulus.

Location	Pressure 100kN/m^2		Pressure 200kN/m^2		Pressure 400kN/m^2	
	E_c Measured	E_c predicted	E_c measured	E_c Predicted	E_c Measured	E_c Predicted
Eagle island	5.347	5.209	8.620	8.519	15.625	15.559
Rumuigbo	5.917	5.944	8.130	8.244	12.658	13.444
Agip	5.347	5.135	8.695	8.535	13.888	14.135
Abuloma	2.638	2.125	3.831	3.925	10.753	9.925
East west road	5.494	5.172	7.752	7.632	12.987	12.672
Port Harcourt Town	6.849	6.791	9.708	9.901	16.666	15.501

$+ 2.039$, $R^2 = 0.997$ (15)

Rumuigbo: $1/m_v = 1E\text{-}07p^3 - 6E\text{-}05p^2 + 0.034p + 3.044$, $R^2=0.990$ (16)

Agip: $1/m_v = -2E\text{-}05p^2 + 0.040p + 1.335$, $R^2=0.993$ (17)

Abuloma: $1/m_v = 4E\text{-}05p^2 + 0.006p + 1.125$, $R^2=0.993$ (18)

East West Road: $1/m_v = 2E\text{-}06p^2 + 0.024p + 2.752$, $R^2=0.988$ (19)

PortHarcourt Town: $1/m_v = 3E\text{-}08p^3 - 3E\text{-}05p^2 + 0.044p + 2.061$, $R^2=0.993$ (20)

Model Calibration

In tables 1-3 the models calibration results are presented and generally, a reasonable positive correlation on measured values to predicted values were obtained, except for cases of m_v at pressure of 400kN/m^2.

CONCLUSION

Based on the study the following conclusions can be drawn:

1. The predictive models generated for the areas gave values that reasonably compares with measured values.
2. Foundation settlement input parameters of void ratio, coefficient of volume compressibility and compression modulus of soils in studied areas can easily be obtained from generated predictive models for preliminary analysis and design of shallow foundations placed on cohesive soils.

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